

Deconvolution

At the end of this Session, you will be able to:

- **Define the term 'reflectivity series'**
- **Define the term 'convolution'**
- **Define the term 'deconvolution'**
- **Define the term 'seismic wavelet'**
- **State a mathematical equation that describes the convolutional model in terms of the following components: recorded seismogram, basic seismic wavelet, earth impulse response, random ambient noise.**
- **Define the term predictive deconvolution**
- **Define the term gap length**
- **Define the term total operator length**
- **Describe how gap length selection affects the success of deconvolution processing**
- **Describe how total operator length selection affects the success of deconvolution processing**

At the end of this Session, you will be able to:

- **Define the term 'pre-whitening' as used in deconvolution processing**
- **Describe how the use of pre-whitening can improve results of deconvolution processing**
- **Define the relationship between pre-whitening level and seismic data bandwidth**
- **Define the term 'white noise' as used in deconvolution processing**
- **Define the term 'spiking deconvolution'**
- **Describe at least 3 ways in which application of pre-stack deconvolution can improve the quality of seismic data.**
- **Describe at least 2 ways in which application of post-stack deconvolution can improve the quality of seismic data.**
- **Define the term 'deterministic deconvolution'**
- **Define the term 'statistical deconvolution'**

At the end of this Session, you will be able to:

- **Define the term 'multi-window deconvolution'**
- **Explain how multi window deconvolution can be used to improve the quality of data in comparison to single window deconvolution**
- **Define the term 'single channel deconvolution'**
- **Define the term 'autocorrelation'**
- **Define the term 'first zero crossing'**
- **Define the term 'second zero crossing'**
- **Explain how an autocorrelation display can be used to help determine the optimum gap length for deconvolution processing**
- **Explain how an autocorrelation display can be used to help evaluate deconvolution performance for a given dataset**

Agenda

- **Introduction**
- **Deconvolution's wavelet compression theory**
- **Statistical Deconvolution**
- **Deconvolution in Practice**
- **Multiple Removal - Synthetic example.**
- **Deconvolution SFM in Omega**
- **Conclusions**
- **Tau-P Demultiple**

Introduction

- **Deconvolution is a processing tool which has been used for**
 - **Wavelet Shaping**
 - **Multiple Removal**
 - **Noise Attenuation**

Introduction

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 - **Wavelet Shaping**
 - **Multiple Removal**
 - **Noise Attenuation**
- **However**
 - **Occasionally applied without thought as to whether it is actually necessary**
 - **More specialised wavelet processing or multiple attenuation programs may be more appropriate**

Introduction

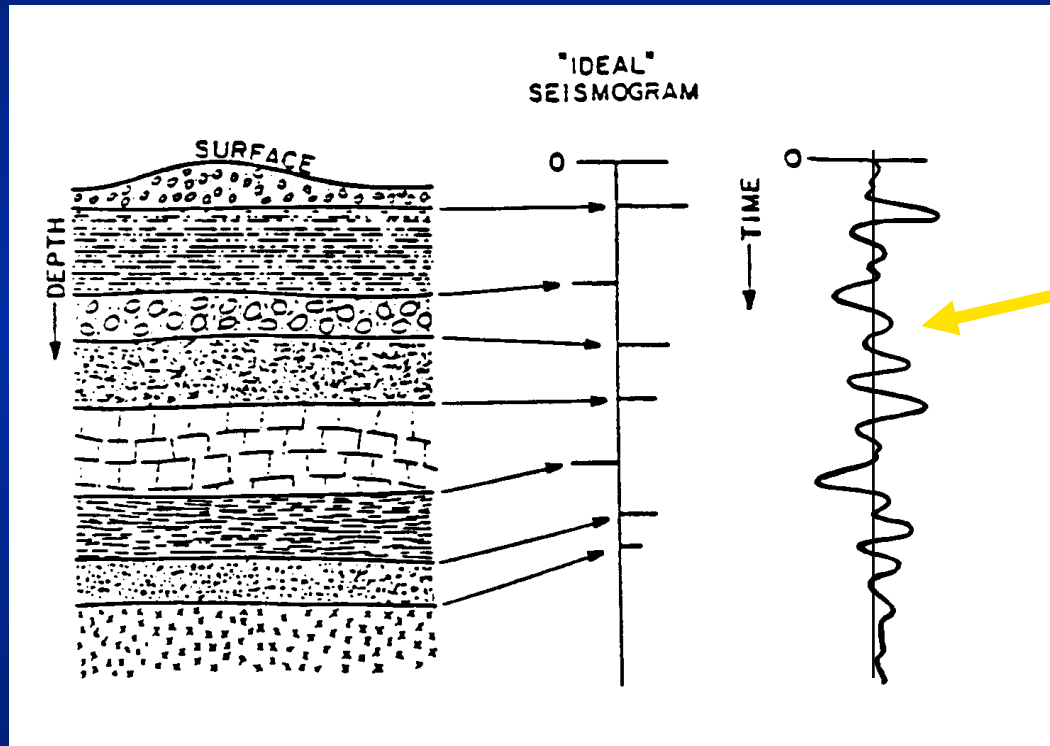
- **Deconvolution is a processing tool which has been used for**
 - **Wavelet Shaping**
 - **Multiple Removal**
 - **Noise Attenuation**
- **However**
 - **Occasionally applied without thought as to whether it is actually necessary**
 - **More specialised wavelet processing or multiple attenuation programs may be more appropriate**
- **Even so, decon is sometimes the most robust and straightforward way of achieving your goals**

Types of Deconvolution

- **Signature**
 - **Predictive Deconvolution**
 - **Surface Consistent Deconvolution**
-
- **Signature is explained in the DPSTART signature presentation, this presentation we will discuss Predictive Deconvolution.**
 - **Surface Consistent Deconvolution is too advanced a process for this course and will be covered in DP2.**

Ideal vs Reality

The recorded seismic trace may be modelled as a series of interactions between the source signature (a finite, band-limited wavelet) and the earth.



A plot of the reflection coefficients of the layers as a function of two way travel time.

Sedimentary
Column

Reflectivity
Function

Convolution

Convolution is the change of a wave shape as a result of passing it through a linear filter

When a signal passes through any filter (such as the earth), it is replicated many times with different amplitudes and time delays, by the filter.

Assuming that the signal, itself, does not alter with the passing of time (ie. it is time shift invariant), then the filter produces a linear superposition of these copies of the signal. The mathematical description of this process is known as convolution.

To revise convolution read the material in the DPSTART lecture on Signal Processing.

Deconvolution

The objective of deconvolution: in theory.....

- to extract the reflectivity component of the seismic trace by removing the effects of the seismic wavelet, including ghosts and short-period multiples.

in practice.....

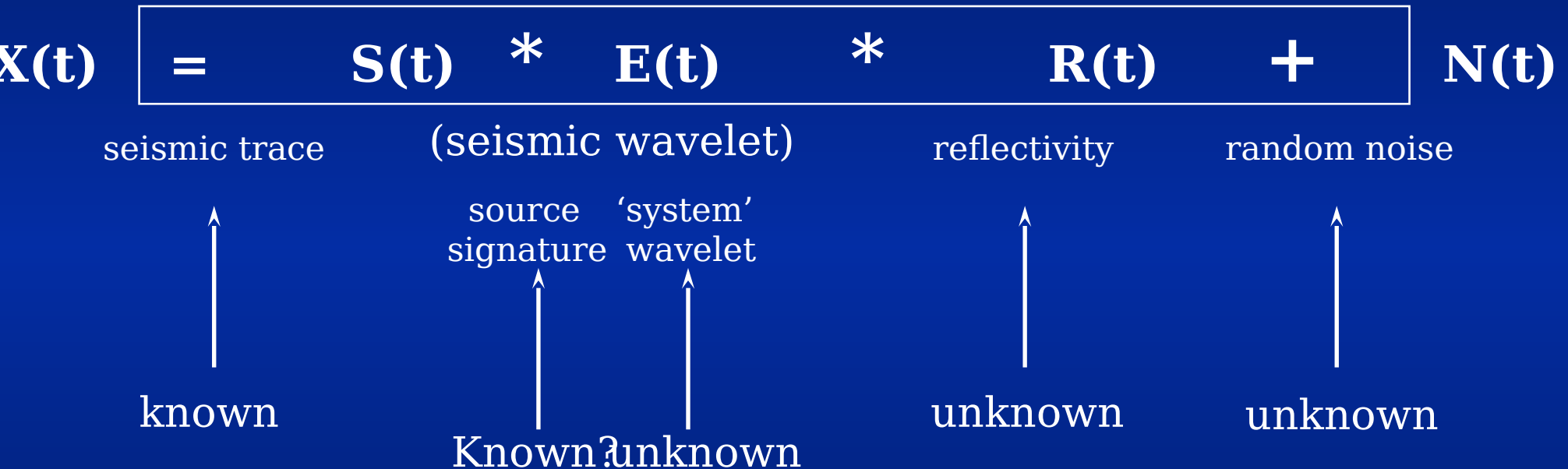
- to arrive at a better estimate of the reflectivity.
- output trace to represent reflectivity functions in terms of amplitude, polarity and depth within limits of seismic signal properties.

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Wavelet Compression in Theory

In deconvolution, the aim is to resolve the reflectivity
 $R(t)$



Wavelet Compression in Theory

In the frequency domain, the equation can be written as:

$$X(f) = S(f) \times E(f) \times R(f) + N(f)$$

where $X(f)$, $S(f)$, $E(f)$ and $R(f)$ represent the amplitude spectra of the corresponding time functions (ignoring the phase for now)

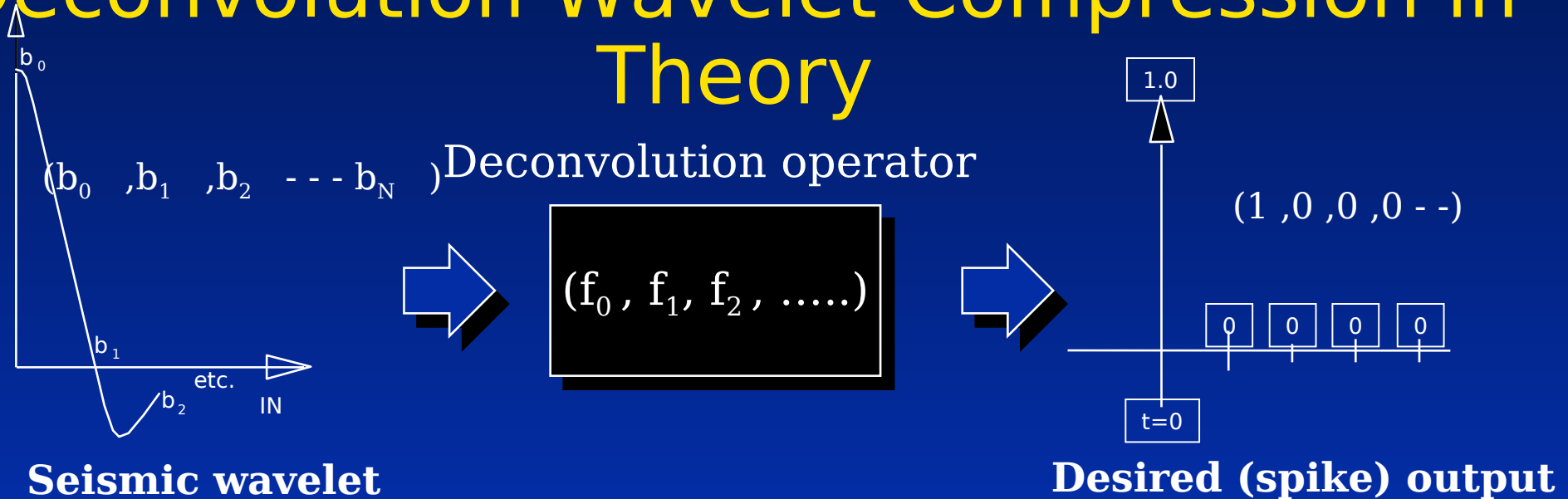
How can we remove the effect of the $(S(f) \times E(f))$ term in this equation?

Make it equal to '1' (or any constant value will do)!

What time function (in the time domain) will have a 'constant' amplitude spectrum at all frequencies?

A. A SPIKE!

Deconvolution Wavelet Compression in Theory



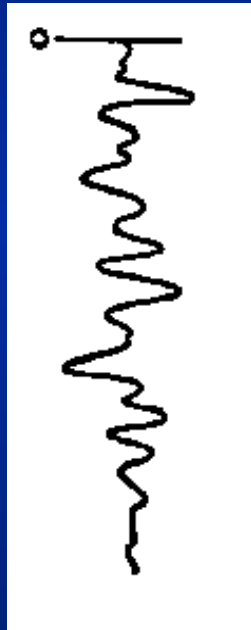
an **inverse filter** to deconvolve the data

In the time domain, deconvolution involves finding an inverse of the wavelet. When the wavelet is deconvolved with the seismic trace, outputs the reflectivity series.

The desired result is that the seismic wavelet is converted to a spike.

Deconvolutional Model

RECORDED
SEISMIC TRACE

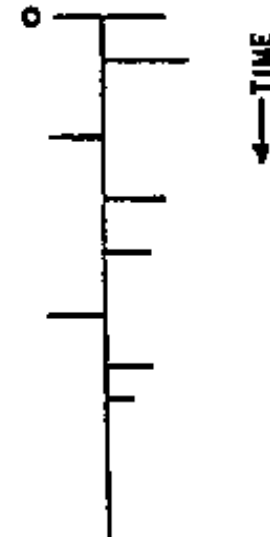


*

DECON
FILTER



REFLECTION
FUNCTION



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Deconvolution Methods

Generally fall into one of two categories -

Deterministic deconvolution

Deconvolution; where part of the seismic system is known. For example, where the source wavelet is accurately known, we can do source signature deconvolution.

Statistical deconvolution

Deconvolution where no information is available about any of the components of the convolutional model. A statistical approach is needed to derive information about a wavelet (either 'source', 'system' or 'combined wavelets').

Statistical Deconvolution

After 'de-signature' we are left with :

$$\boxed{\begin{matrix} \mathbf{X(t)} & = & \mathbf{E(t)} & * \\ \mathbf{R(t)} & & & \end{matrix}}$$

seismic trace system wavelet reflectivity

known unknown unknown

The diagram illustrates the equation $X(t) = E(t) * R(t)$ within a rectangular box. Below the box, the terms are labeled: $X(t)$ is 'seismic trace', $E(t)$ is 'system wavelet', and $R(t)$ is 'reflectivity'. Arrows point from the words 'known', 'unknown', and 'unknown' below to the terms 'seismic trace', 'system wavelet', and 'reflectivity' respectively.

We can now use **Statistical** deconvolution techniques to remove the system wavelet, by compressing it to a spike, and hence derive the reflectivity.

In practice though, the wavelet is not compressed to a spike but simply reduced in length. Remember, predictive deconvolution is also used to reduce multiples & perform no compression.

Statistical deconvolution may be applied without the prior application of deterministic deconvolution, as is usually the case with land data.

Statistical Deconvolution

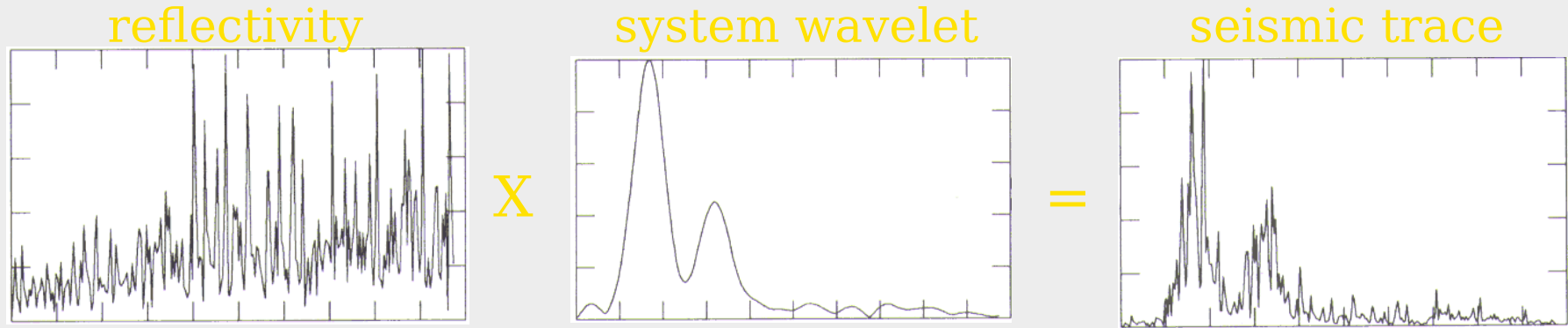
Statistical deconvolution is a process where we :

- have no pre-knowledge of the wavelet
- derive information about the wavelet from the data itself, specifically from the **autocorrelation** of the data.
- make certain assumptions about the data which justify the statistical approach.

Assume the autocorrelation of the seismic trace is equivalent to autocorrelation of the system wavelet and use Wiener-Levinson algorithm to derive the deconvolution filter.

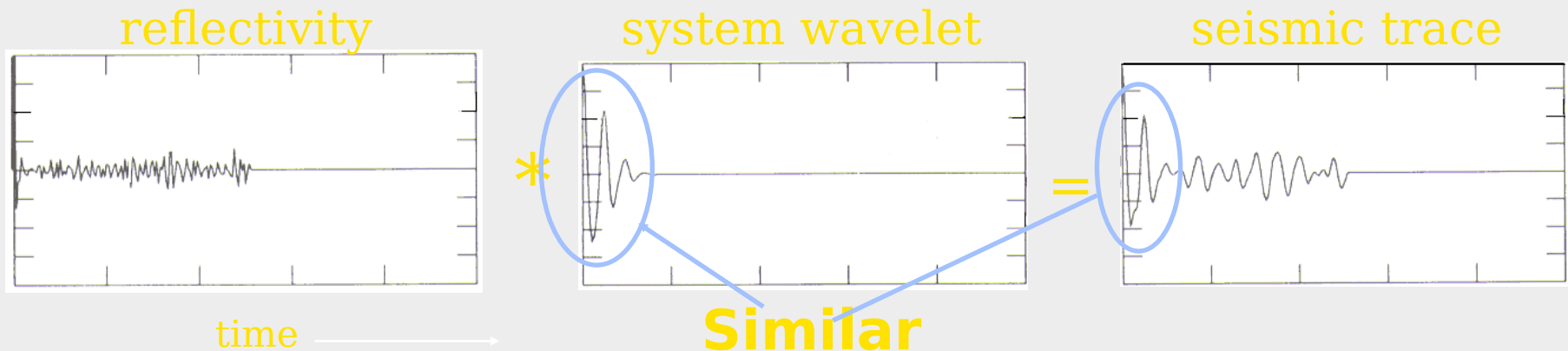
Auto-correlation – another look

Amplitude spectrum



Note the autocorrelation of a seismic wavelet and trace are similar over early part of the trace

Auto-correlation

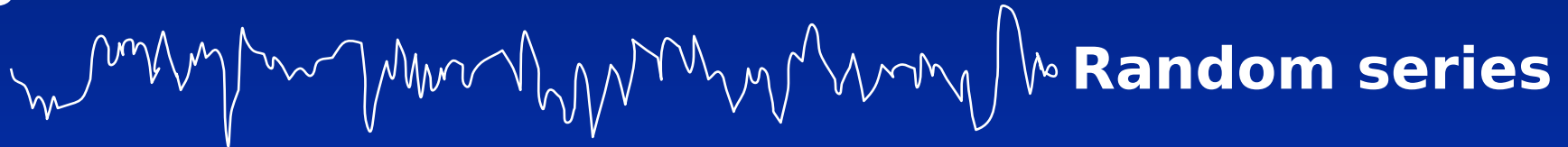


General Assumptions

- **Deconvolution is reliant on four major assumptions**
 - **Random Reflectivity Series**
 - Autocorrelation is a spike
 - **Stationary (i.e.. time invariant) wavelet**
 - short design windows
 - long design windows
 - **Minimum phase wavelet**
 - importance of this assumption depends on decon gap
 - **Noise component is low enough to be ignored**
 - So we need to remove as much noise as possible before decon

Random Time Series

a perfectly random time series, like white noise as shown. Its auto-correlation will be a spike at zero lag, since random series correlate itself perfectly at zero lag and will be perfectly uncorrelated at other time lags.

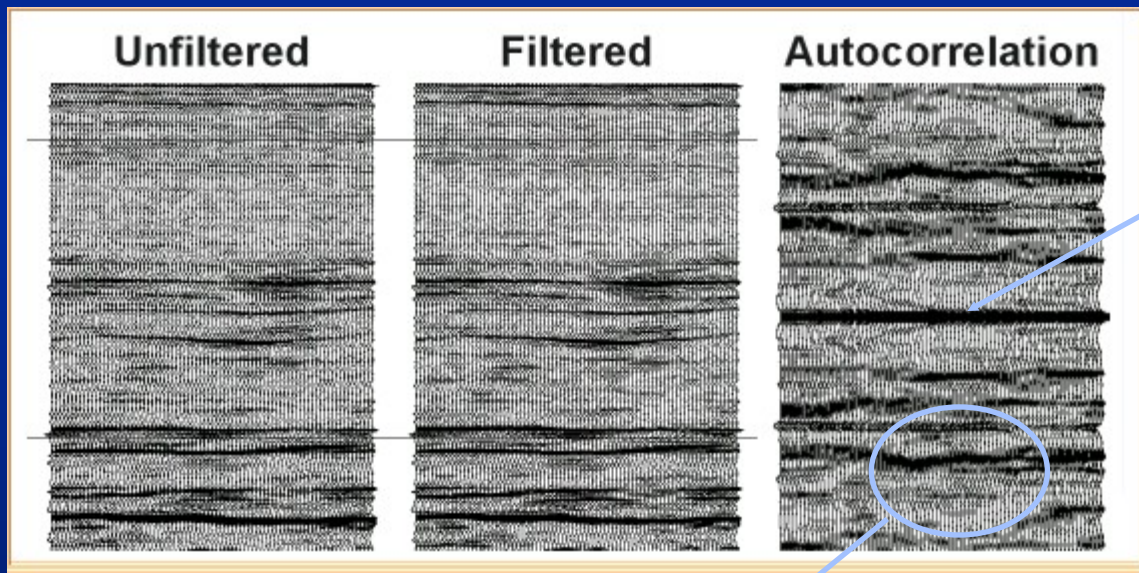


Statistical deconvolution techniques are based on the assumption that the earth's reflectivity is also random and that its auto-correlation is therefore a *spike*

Random Time Series

andom time series assumption is not met, the deconvolution
ove reflections that it sees as periodic, and will also intro
imes.

No decon filter applied



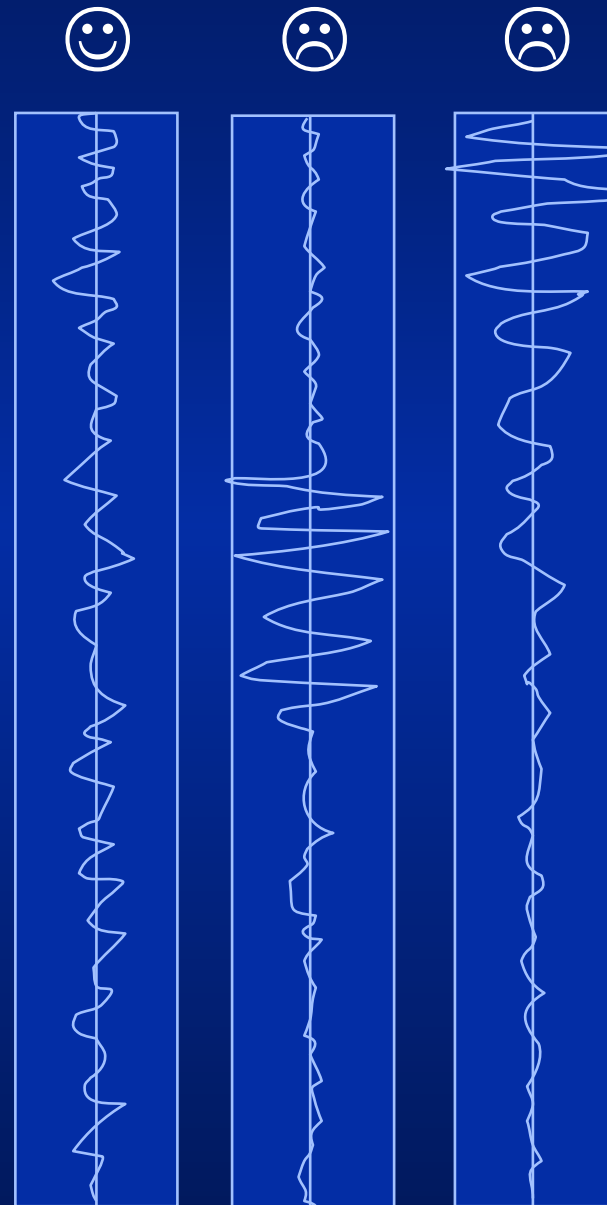
Spike at centre
of
autocorrelation

Normally we
only display
half the auto-

fore autocorrelation energy is assumed to be a multiple ene
because it is
symmetrical.

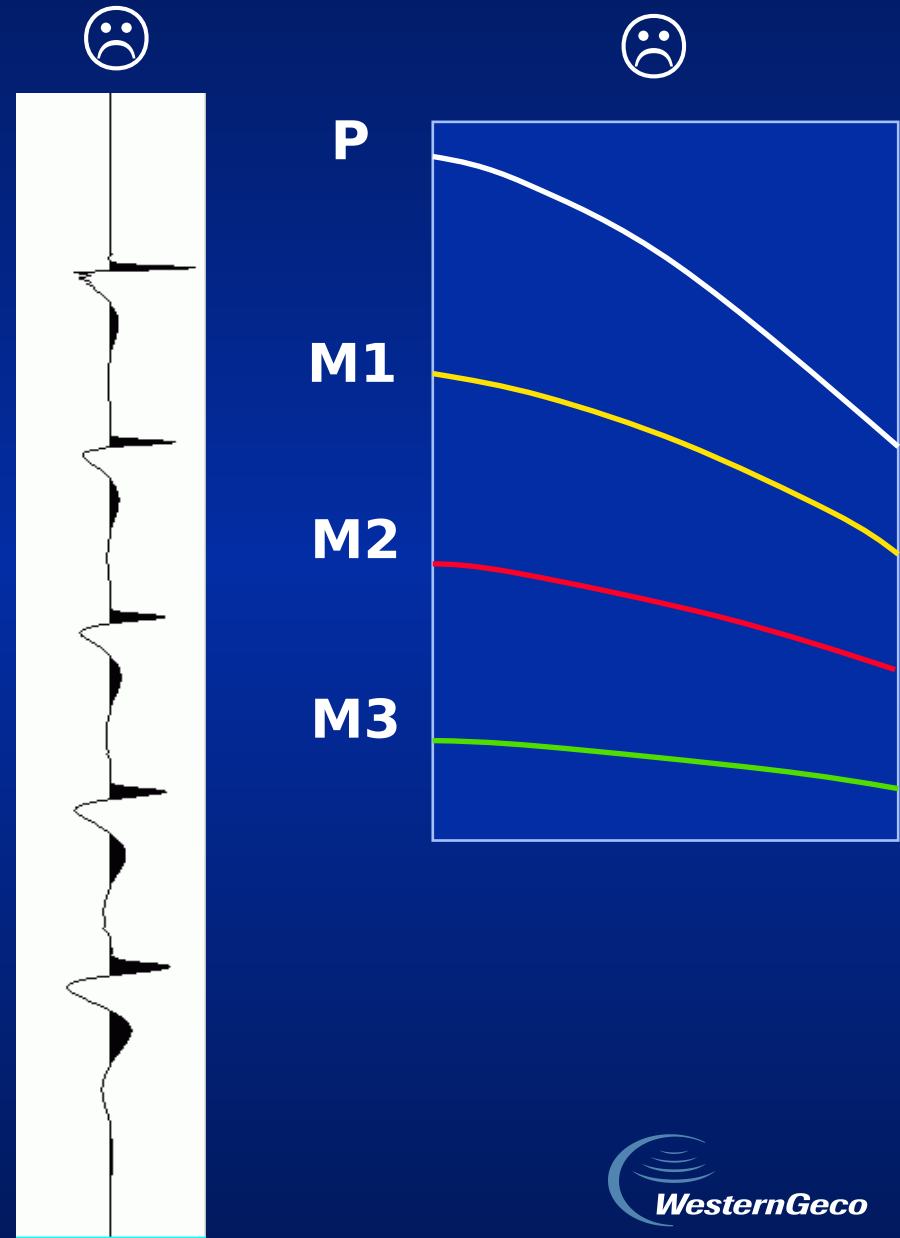
Stationary Wavelet Assumption

- **White reflectivity assumption**
 - **Use long windows (10% rule)**
 - **Data within the design window must be well balanced**
 - use geospread
 - use expgain if necessary (be careful with multiples)
 - try to exclude areas of very strong reflectivity



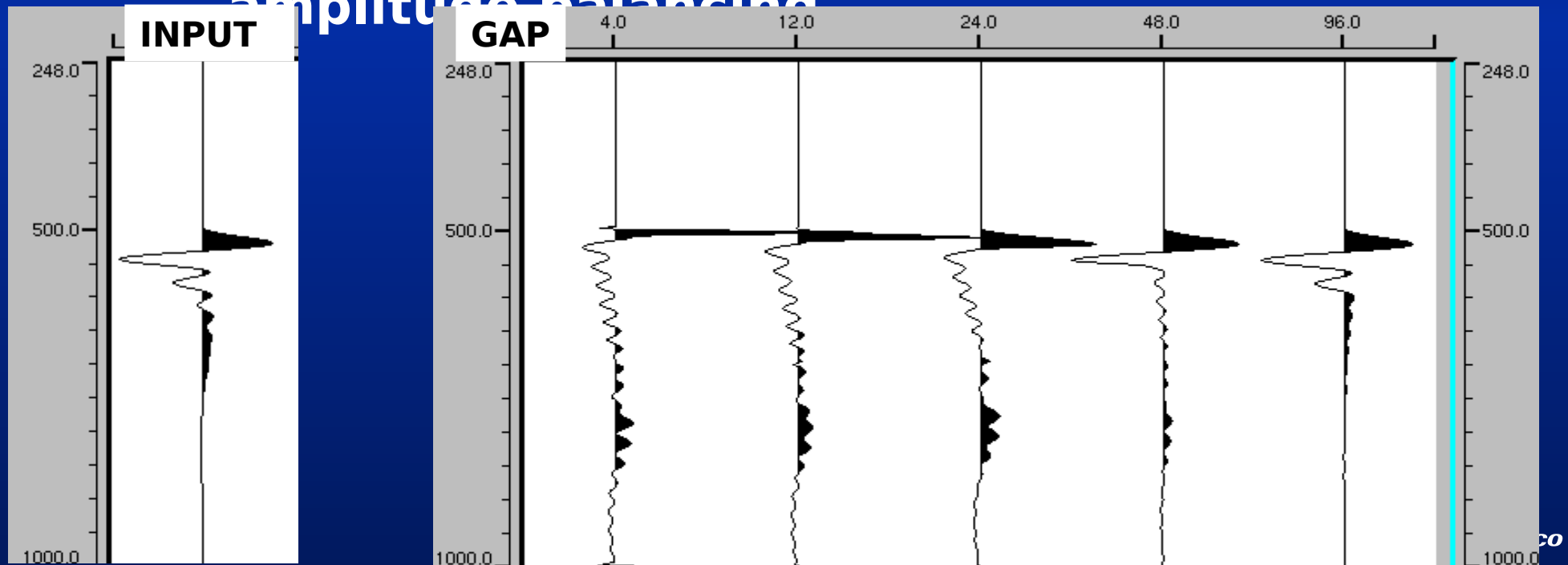
Stationary Wavelet Assumption

- **Stationary wavelet**
 - Wavelet (and multiple period & amplitude) should not change within the design window
 - choose windows carefully
 - use multiple windows
 - consider using more appropriate sfms



Minimum Phase Assumption

- Minimum phase assumption
 - Long-gap decons don't modify wavelet
 - wavelet phase is less important
 - Multiples must be minimum phase
 - don't distort them with badly chosen amplitude balancing



Statistical Deconvolution

Two most common examples -

- Predictive Deconvolution- uses information from the earlier part of the seismic trace to predict and deconvolve the latter part of the trace. This method is also known as 'Gapped Deconvolution'.
 - Predictive Deconvolution can be used to attenuate multiples, and less commonly these days shape the wavelet.
- Spiking Deconvolution- is a special case of predictive deconvolution where the 'gap' is one sample interval

Statistical Deconvolution - 'Spiking'

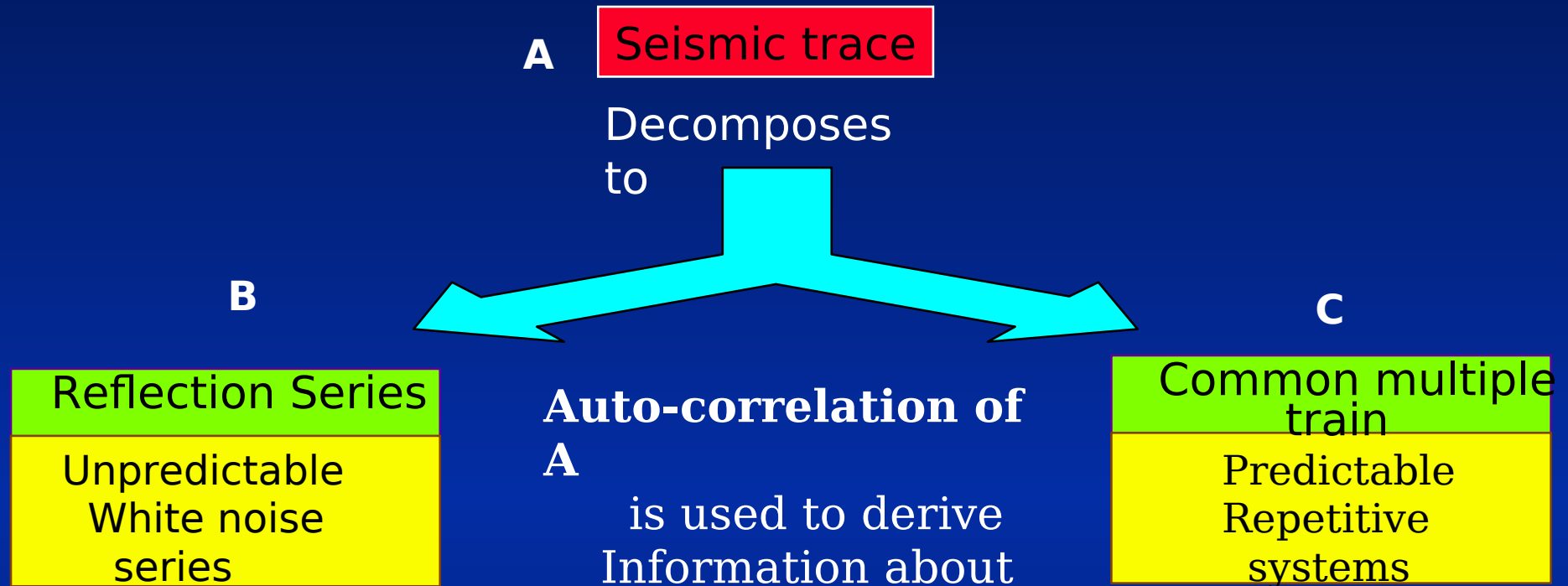
$$\begin{array}{ccccc} \mathbf{X(t)} & = & \mathbf{W(t)} & * & \\ \text{seismic trace} & & \text{seismic wavelet} & & \text{reflectivity} \end{array}$$

use $\mathbf{E(t)}$ in the above equation if deterministic deconvolution had been used.

Now that the ideal wavelet would be a spike (1,0,0,0...) - this would result in the seismic trace being a good representation of the reflectivity function.

to achieve this by applying '**Spiking Deconvolution**'.

Statistical Deconvolution - 'Predictive'



Predictive deconvolution 'predicts' the repetitive element within the seismic trace (multiples, ringing etc) and generates an operator (of a specific length) which will remove them, leaving only the random element i.e. the reflection series.

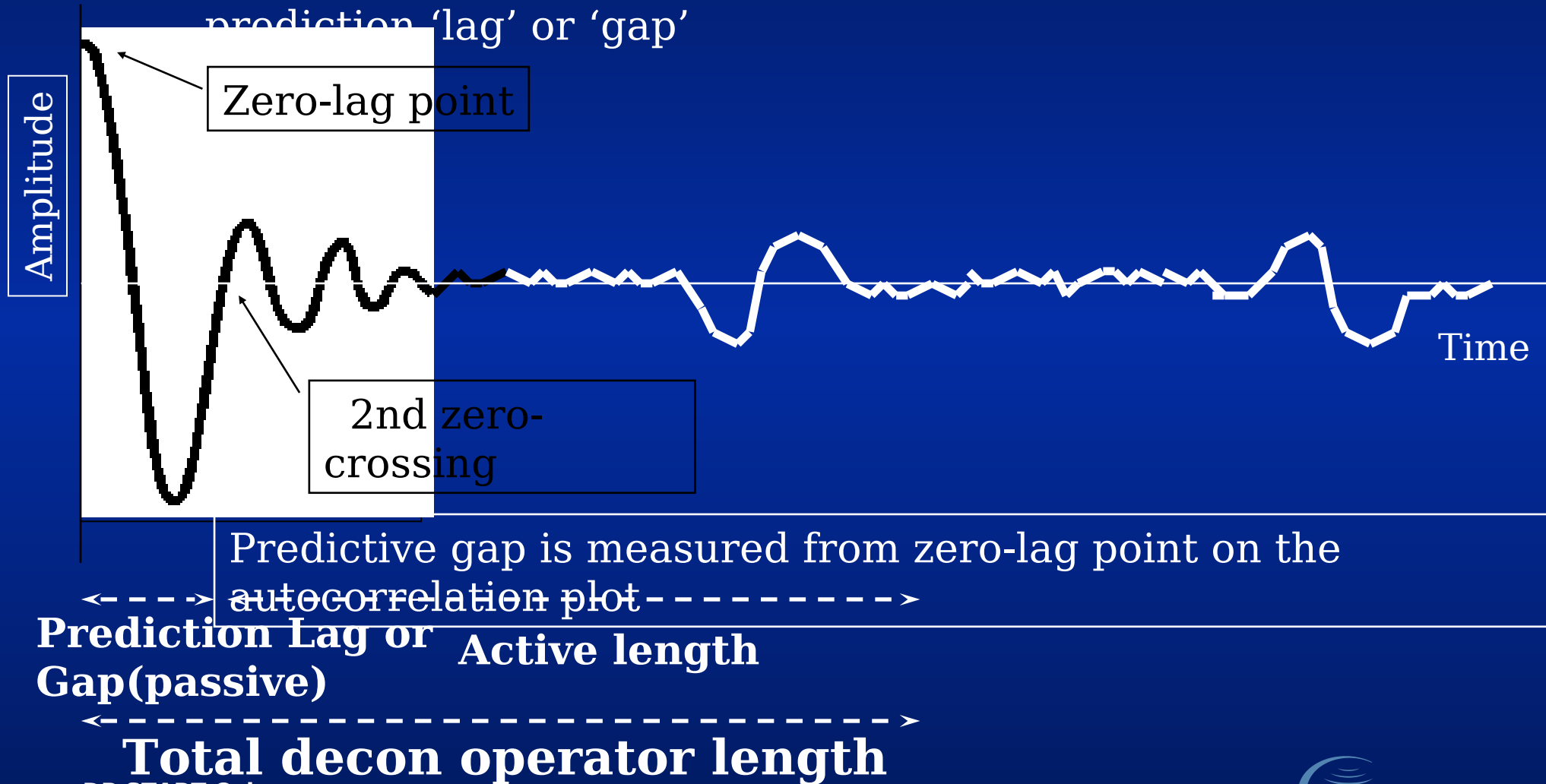
Predictive deconvolution uses information from the earlier part of the seismic trace to predict and

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Key Components of Decon Operator

We can delay the point on our wavelet where our deconvolution operator begins to operate - via the prediction 'lag' or 'gap'



Deconvolution in practice

Gap length

Will have effect on -

- pulse stabilisation - to 'equalise' the basic wavelet throughout the data
- wavelet compression - degree of 'spiking'
- Occasionally, which multiple system is targeted - long gap length with short active operator to straddle long period multiples

(Too long a gap may result in short period reverberations remaining)

Deconvolution in practice

Active operator length

- If the assumption that the auto-correlation of the seismic trace is equal to the auto-correlation of the system wavelet is correct, then the length of the operator is not so critical
- However, if we make the operator too long, we may end up distorting the very information we are trying to extract.
- Deconvolution operator length parameters are arrived at after extensive testing.

Deconvolution in practice

Operator Design Window

This is the length of input seismic data (shot or CMP gathered) that will be auto-correlated In order to determine the length and the shape of the *deconvolution Operator*.

- Must be long enough to 'predict' the multiples targeted!
- **Design window (or gate) usually at least 10 times the operator length.**
- **First break noise is excluded from the design window**
- **One or two derivation windows at the most (multi-window**

Spiking or Gapped Deconvolution?

- Spiking

- **Maximum resolution -**
- **better estimation of reflectivity?**
- **Loss of apparent continuity compared to gapped deconvolution?**
- **Possibility of boosting noise?**
- **To be fully effective, wavelet must be minimum phase**

- Gapped

- **Control of resolution via gap size -**
- **can leave the wavelet unchanged**
- **Can be used solely for multiple suppression.**
- **Less possibility of boosting noise**
- **Minimum phase assumption not so critical_**

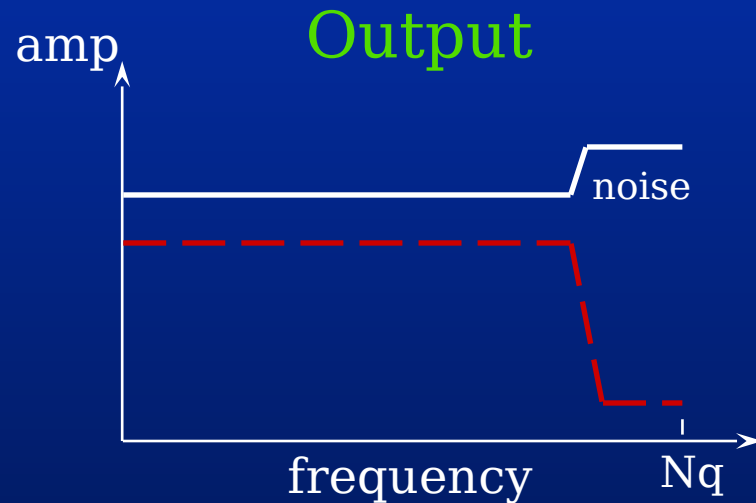
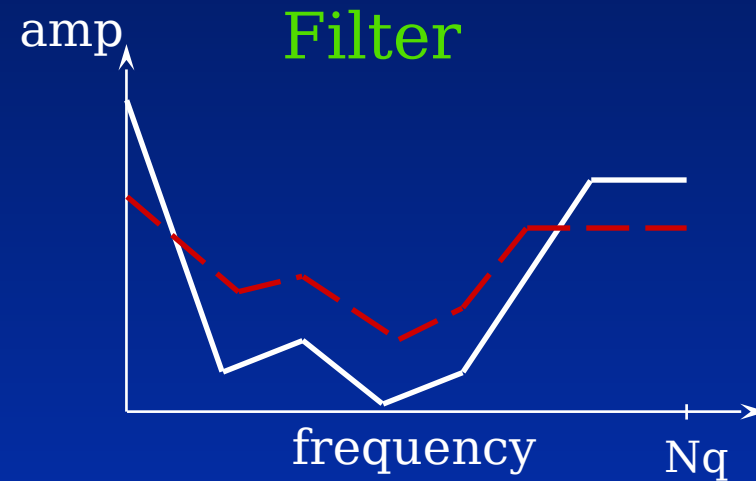
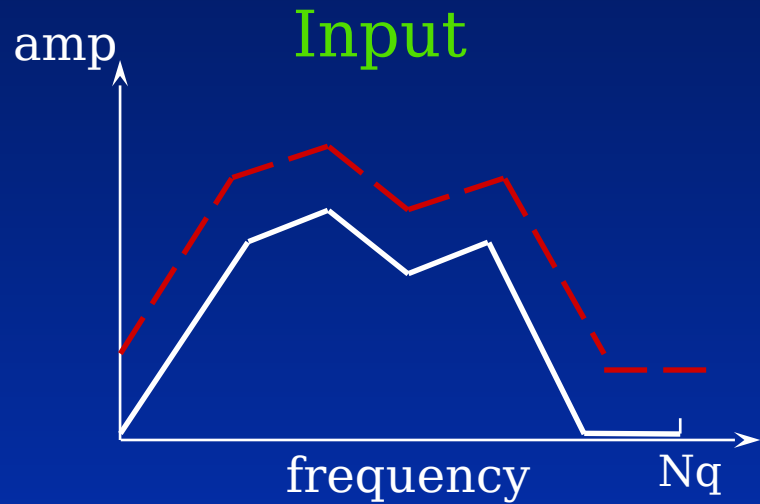
Deconvolution in practice

Pre-whitening

Addition of white noise to data (autocorrelogram) during operator design. It is achieved by adding a constant to the zero-lag of the Autocorrelation function to prevent:

- Numerical instability (divisions by zero when calculating wavelet inverse) during the design of an operator.

Pre-whitening



Pre-whitening

The amount of white noise to add will generally be in the range

0.1 % - 1.0 %

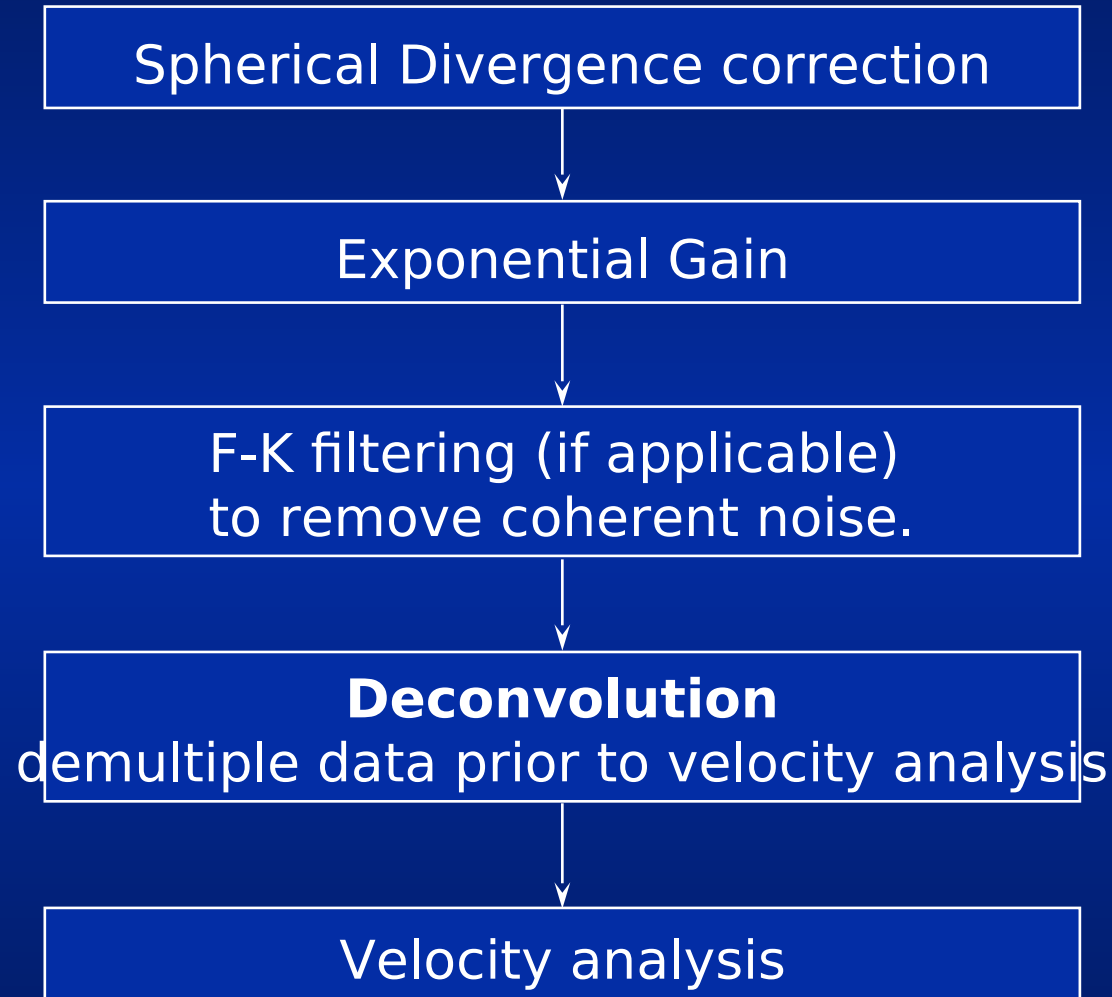
- **Too little white noise may -**
 - **cause the deconvolution operator to become unstable**
 - **decrease S/N ratio of the data**
- **Too much white noise may -**
 - **decrease the effectiveness of the deconvolution process**
 - **narrow the bandwidth of the data**

Deconvolution in practice

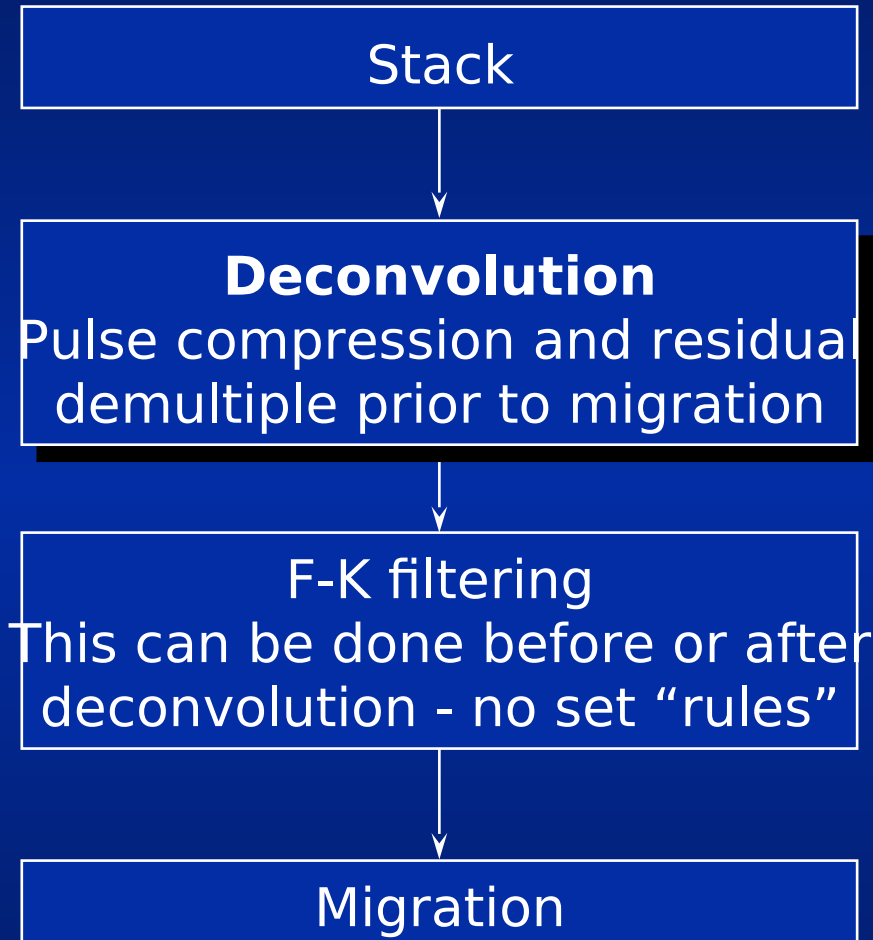
Effects of random Noise

- Random noise in the data itself can have a similar effect to pre-whitening.
- Increasing random noise decreases the effect of deconvolution
- Can result in spurious 'spikes' in the data and amplitude spectrum
- Presence of random noise should mean minimal pre-whitening

Where Pre-Stack ?



Where Post-Stack ?



Deconvolution in practice

Generally

If “tight” compression or spiking is to be done, it is done after stack when the signal to noise ratio has been improved.

Otherwise, the risk with the spiking approach is that noise levels are boosted as well as the signal.

Stacking enhances residual multiples left by pre-stack deconvolution, hence we normally need to do some form of demultiple after stack as well as before stack

Deconvolution in practice

Multi-window deconvolution

- Sometimes the time-variant character of the seismic wavelet tends to violate the assumption that the wavelet is stationary in time and depth.
- In such cases, multi-window deconvolution is advantageous.
- For best results (where necessary) we must design different deconvolution operators from different parts of the record and apply them to corresponding time gates (windows).

Deconvolution in practice

Multi-channel deconvolution

Sometimes advantageous over single-channel deconvolution

- More 'randomness' in the data due to differential moveout
- Noise changes from trace to trace - more randomness
- Noise cancellation within 'noisy' data

However, disadvantages such as smearing of the extracted wavelet can occur

Agenda

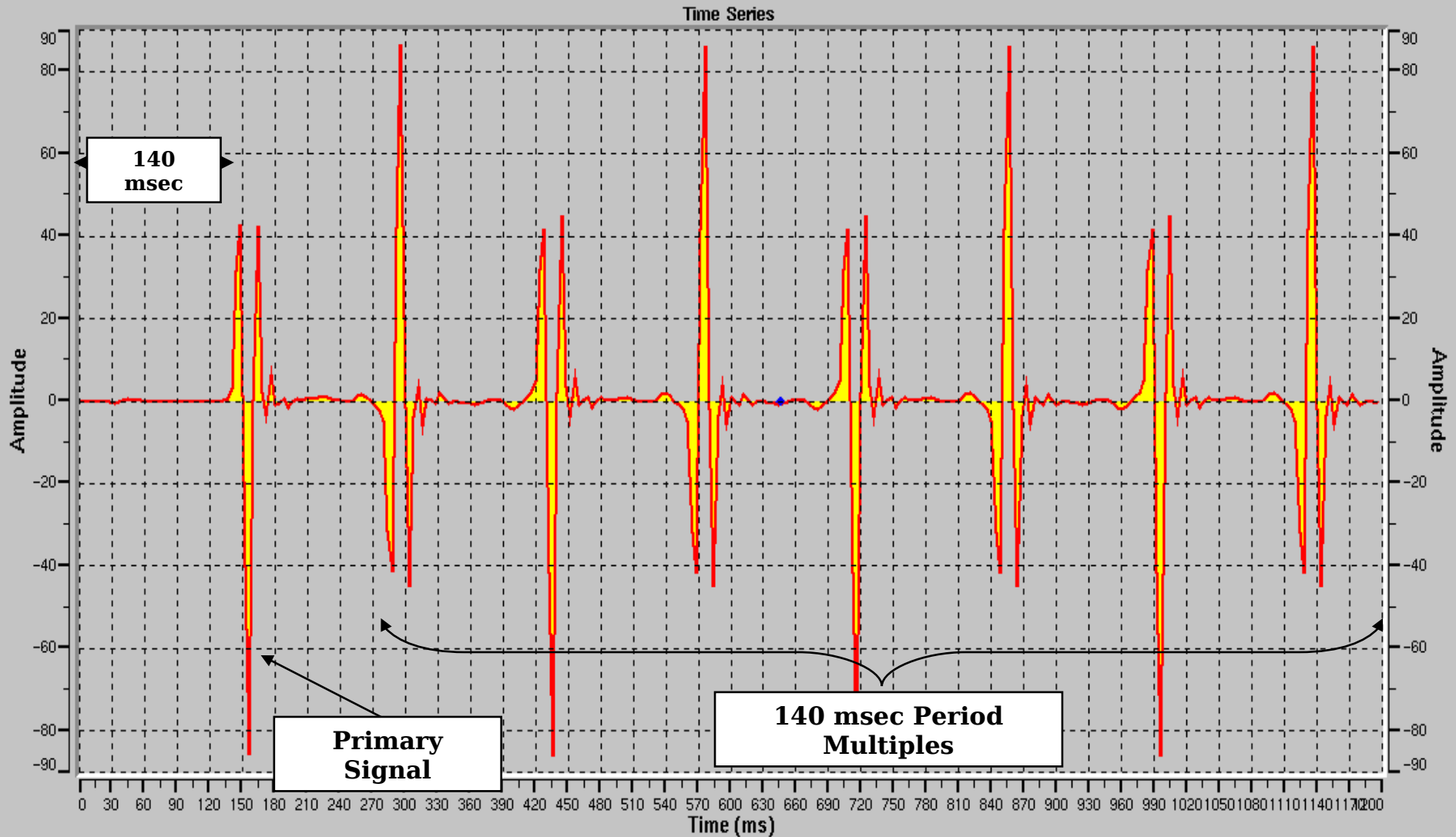
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Deconvolution Operator Example

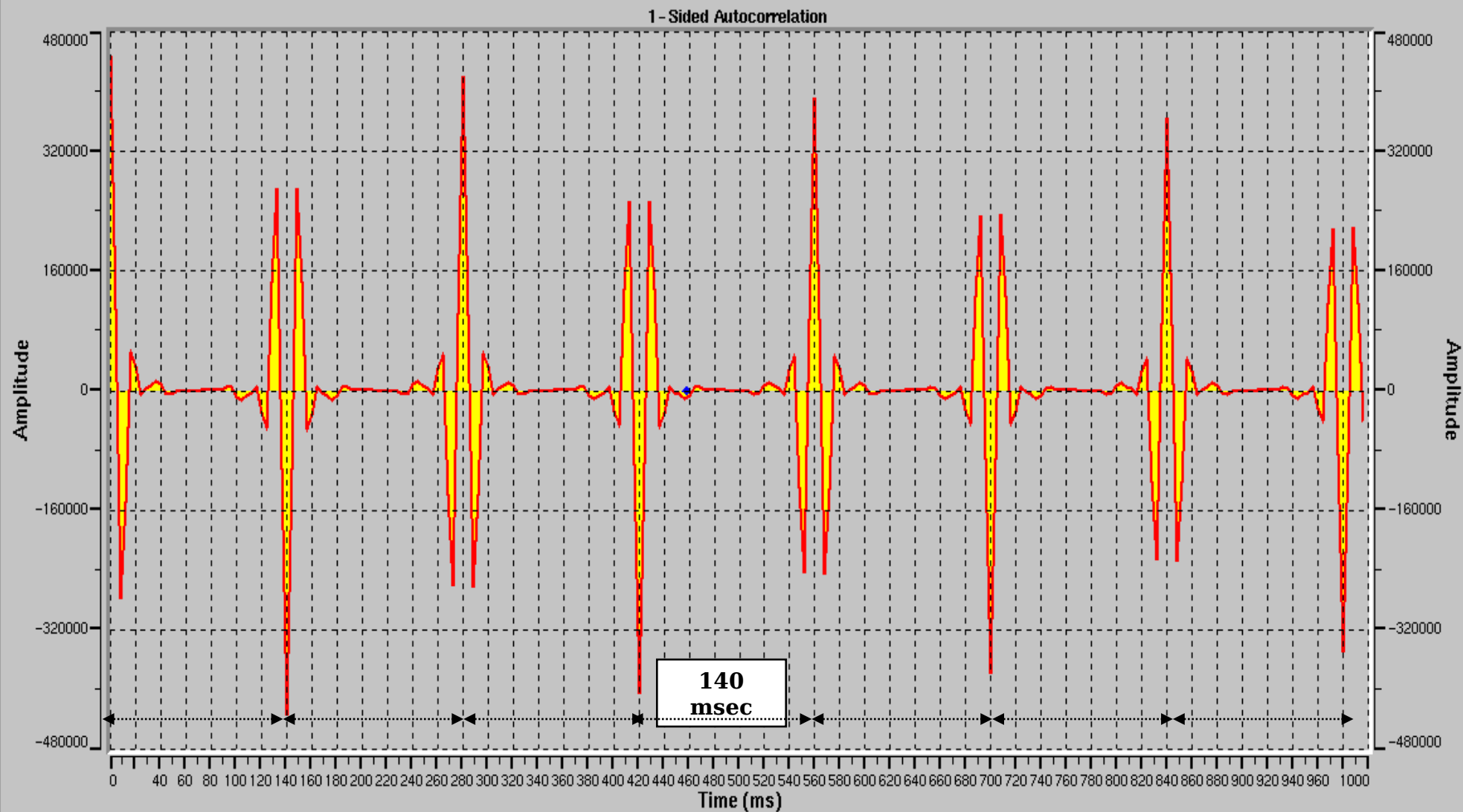
- Let us first detail what the key components of a typical deconvolution operator are.
 - Prediction distance or 'gap'
 - Active operator length
 - Total operator length
- The following slide shows that the total operator equates to:

Total Operator = Active Operator + Prediction Distance

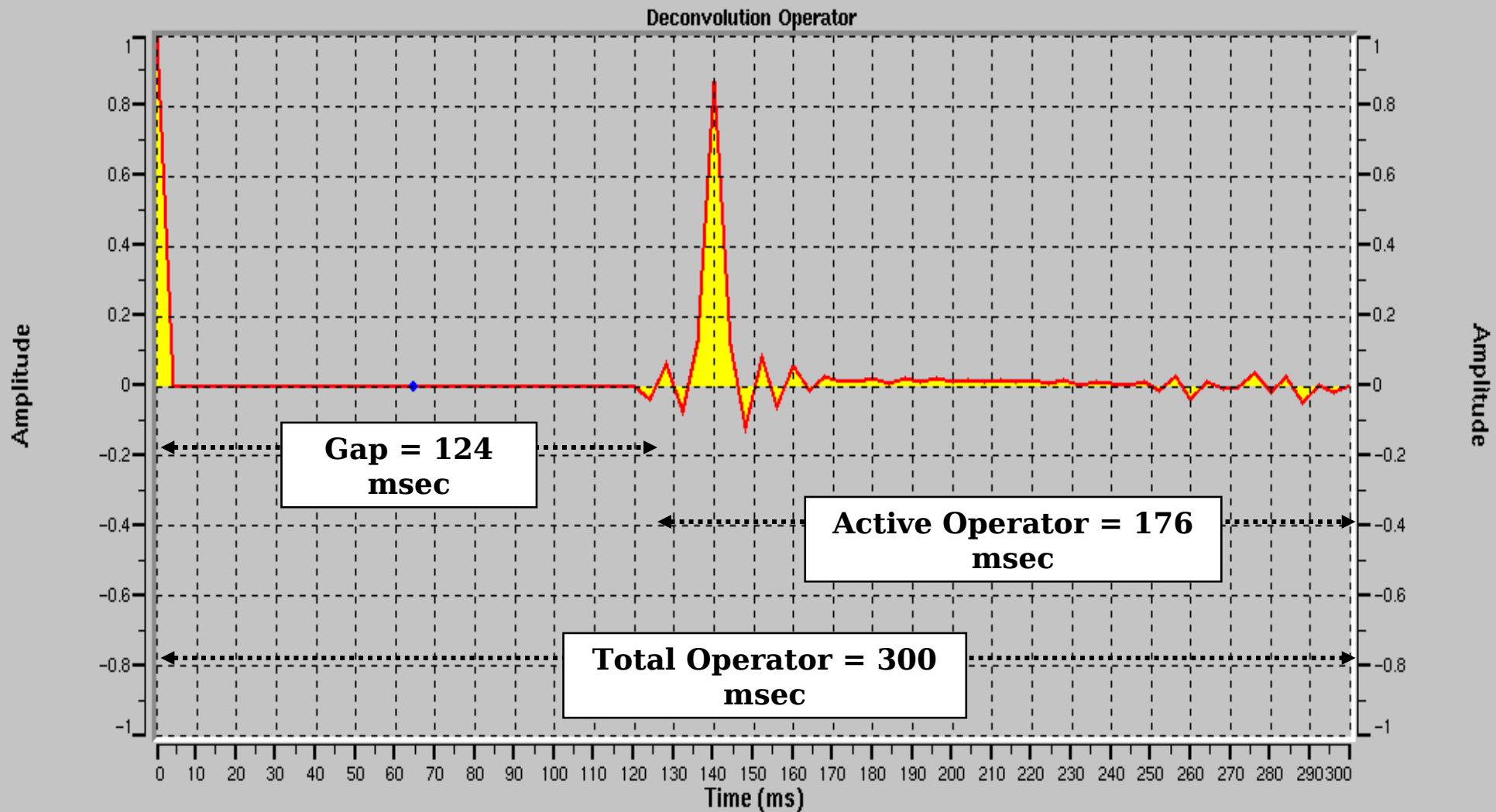
Time Series Containing 140 msec Period Multiples



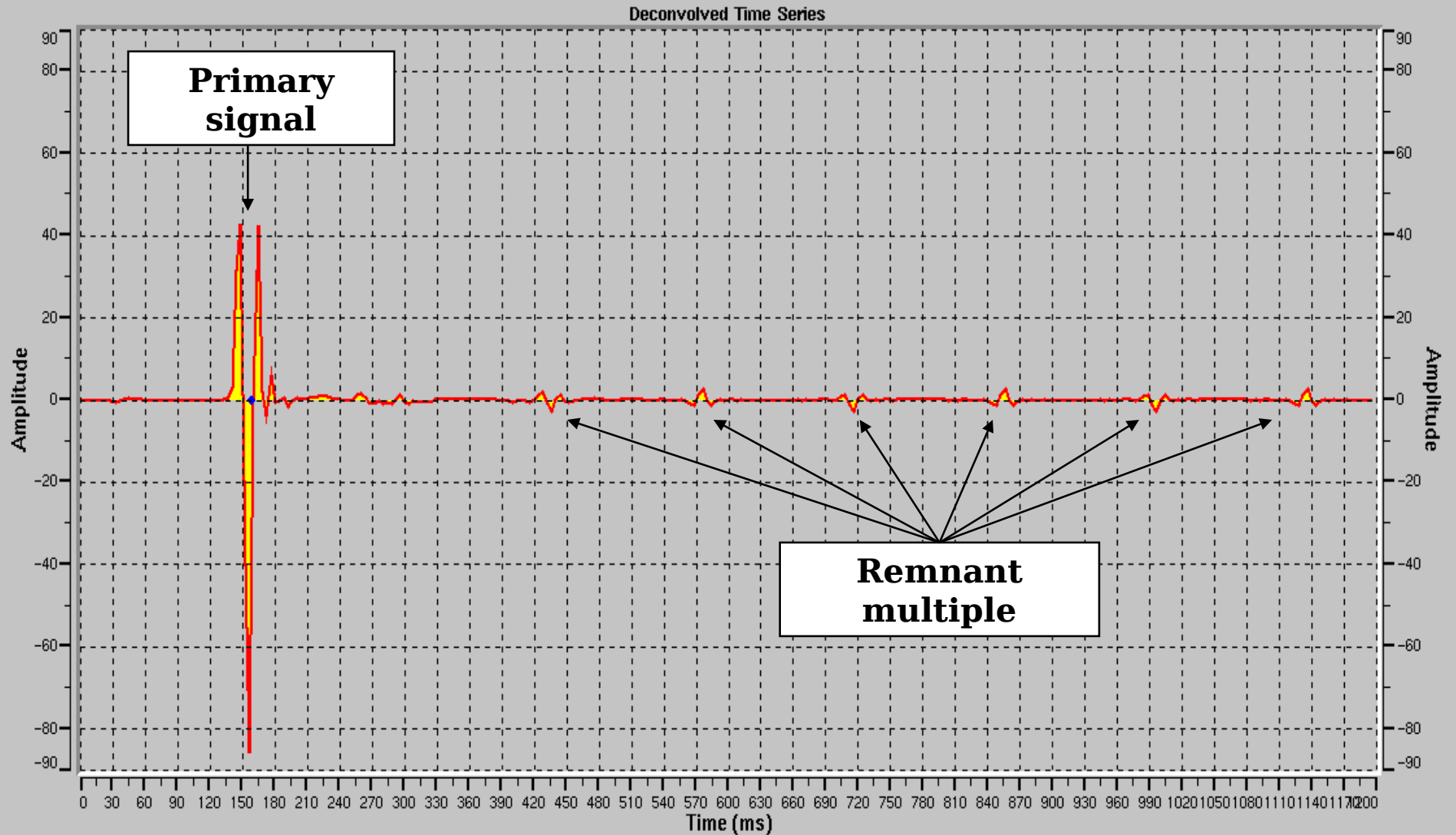
1-Sided Autocorrelation



124/300 msec Deconvolution Operator



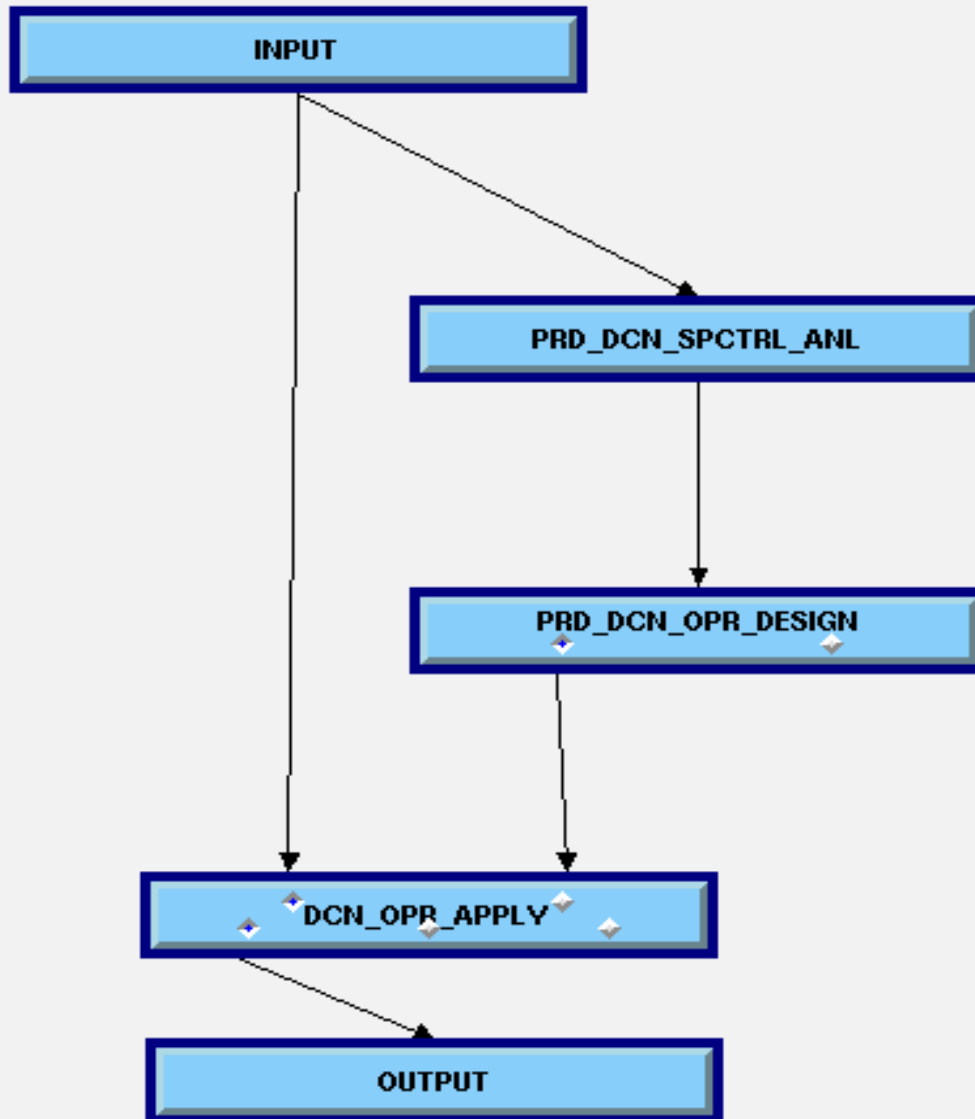
Time Series After 124/300 msec Deconvolution



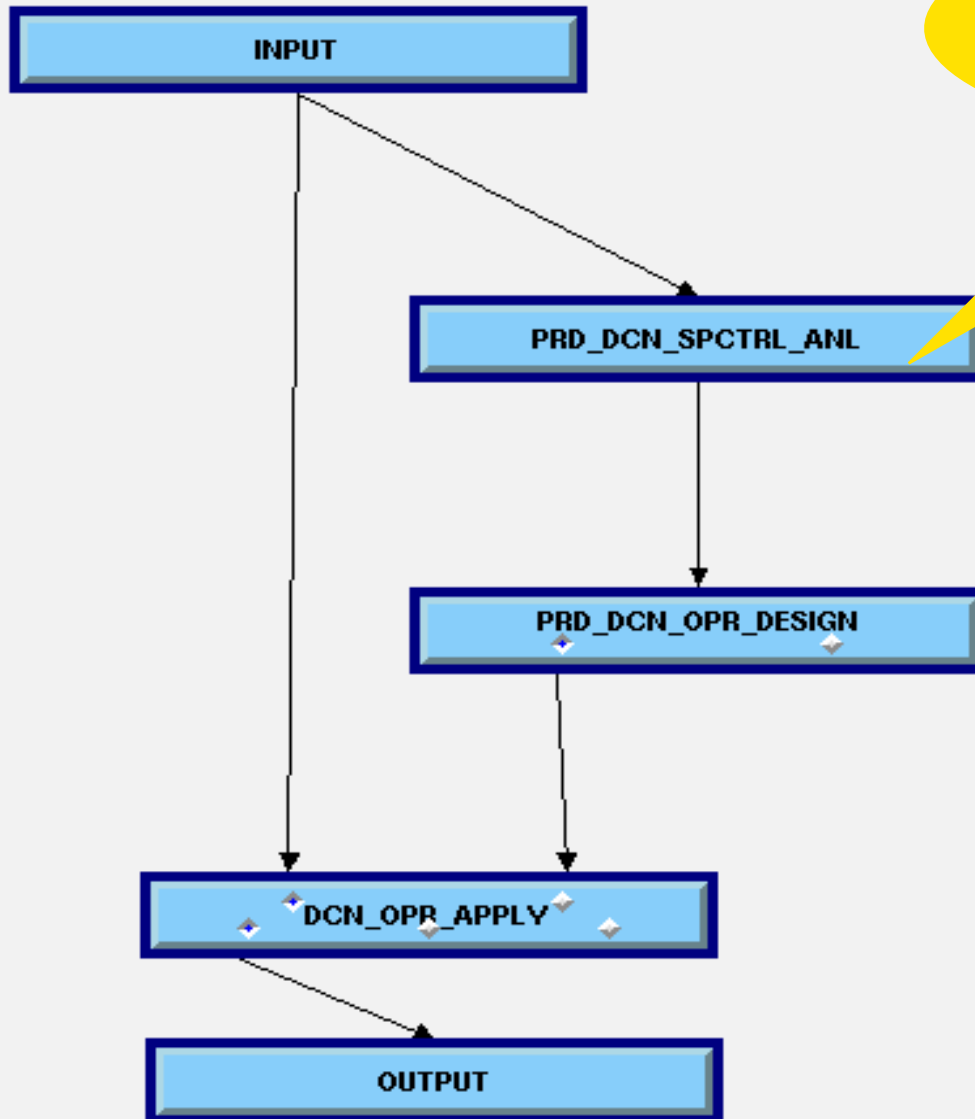
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Predictive Decon - “Normal Flow”

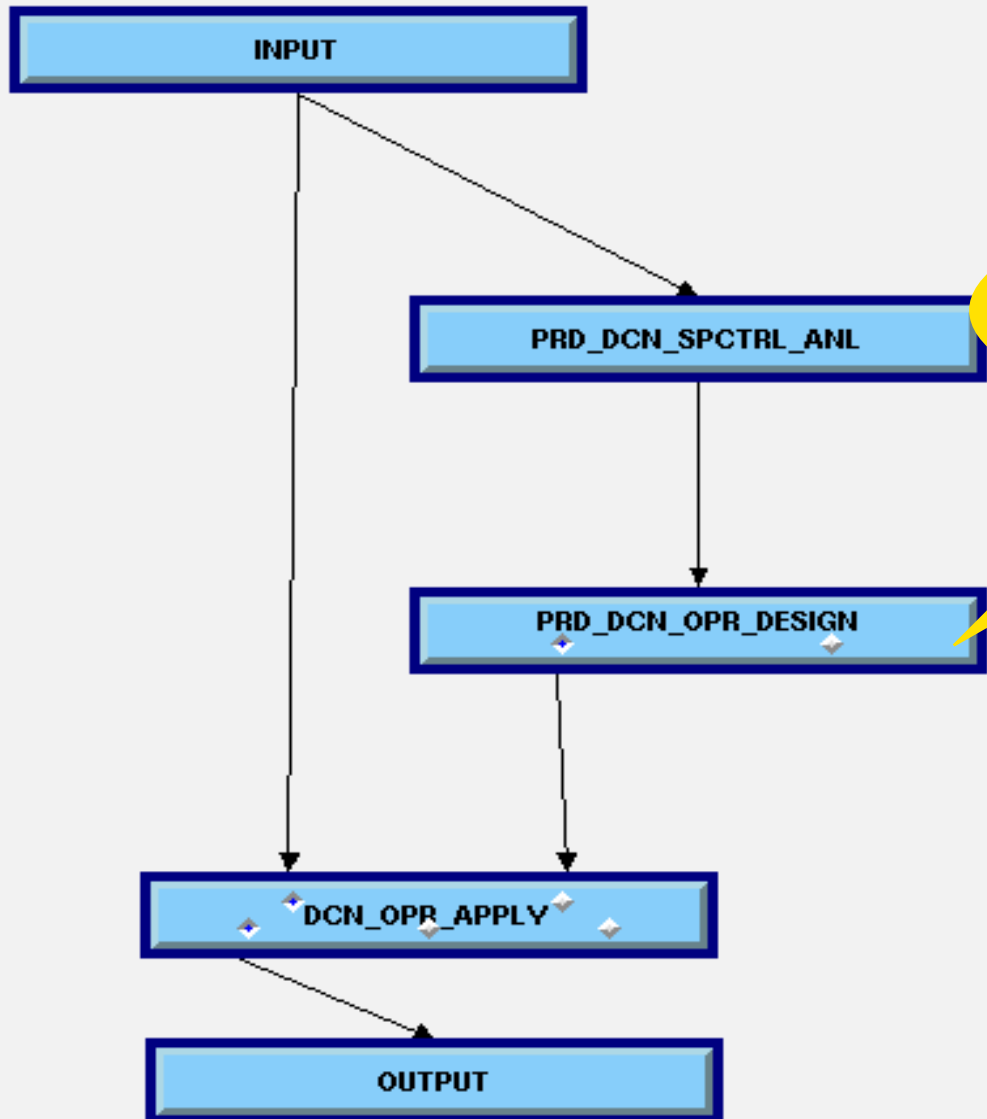


Predictive Decon - “Normal Flow”



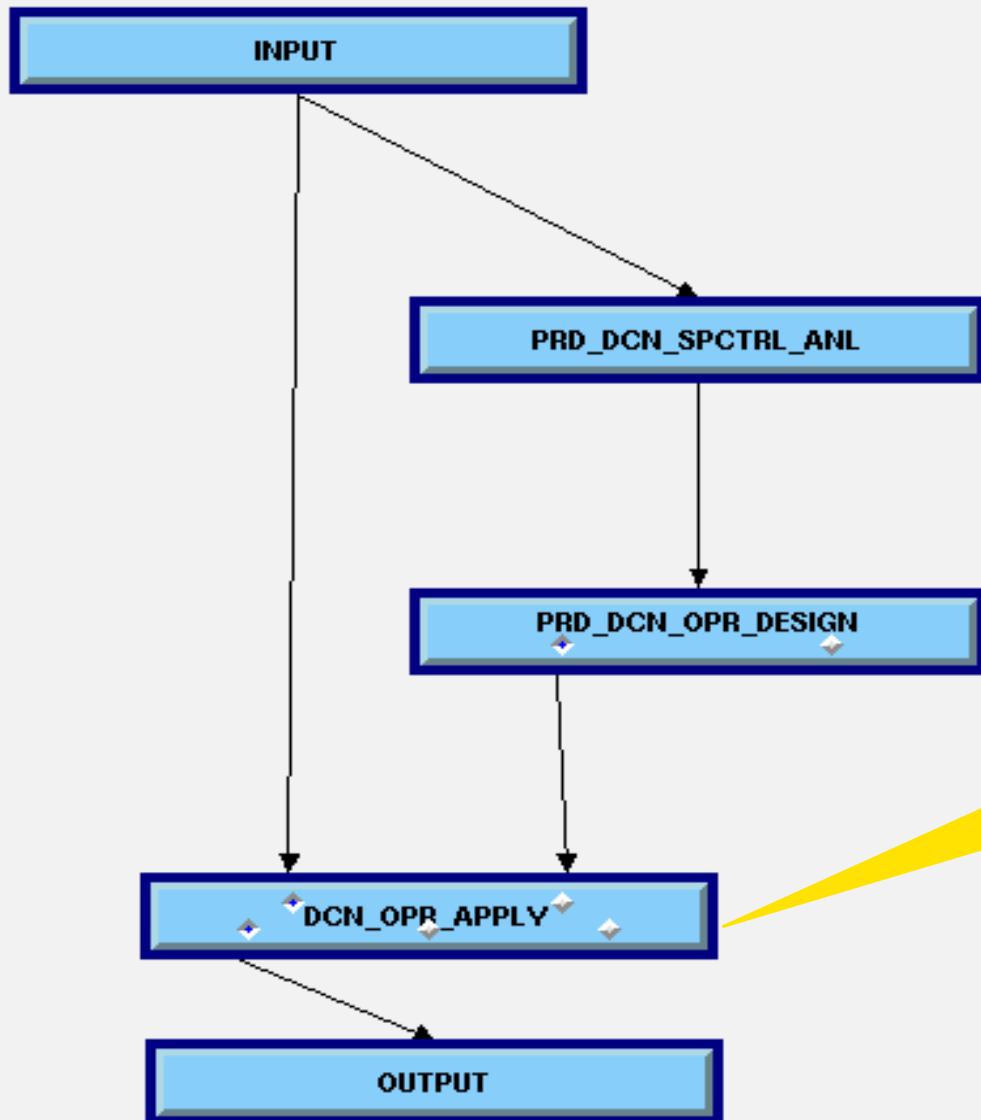
TRACE BY TRACE RAW
ATTRIBUTE

Predictive Decon - “Normal Flow”



**DESIGN OPERATORS
FROM ATTRIBUTES**

Predictive Decon - “Normal Flow”



**MATCH SEISMIC TRACE
TO OPERATOR TRACE
THEN APPLY**

PRD_DCN_SPCTRL_ANL

Predictive Deconvolution Spectral Analysis

Edit Documentation Preferences  Help

Predictive Deconvolution Analysis (Required)

Constant Autocorrelation Half-Length. **300** ☒ USE_WNDW_ACOR_LENGTH

Minimum Window Length Allowed. COMPUTED

The autocorrelation half length specified here, will by default be equivalent to the 'Total Operator Length'

LIST ACTIONS

- * UNITS
- DATA_PRECONDITIONING
- **PREDICTIVE_DECON
- WNDW_ACOR_LENGTH
- SYNTHETIC_INPUT
- * MANUAL_WNDW_DESIGN
- SIMPLE_WNDW_DESIGN
- WNDW_FILE
- * ENVIRONMENT

Parameter Value
Color Legend

User Defined
Line Defined
Survey Defined
Prospect Defined
Write-Up Defined

OK
Cancel

PRD_DCN_OPR_DESIGN

Predictive Deconvolution Operator Design

Edit Documentation Preferences Help

Units (Required)

Units of Time. **MILLISECONDS** **MILLISECONDS** ☐

Prediction Operator Design (Default)

White-Noise Percent.	0.01
Prediction Distance for Each Operator.	32
Override Operator Length for Each Operator.	COMPUTED

'Prediction Distance' or 'Gap'

If the user so desires, the **'Total Operator Length'** may be changed here from the default value which is equal to the autocorrelation half length

LIST ACTIONS

**UNITS
**PRED_OPER
OPER_MODIFY
WNDW_PRED_DIST
COMPUTED_PRED_DIST
WNDW_OPER_LENGTHS
COMPUTED_OPER_LENGTH
* ENVIRONMENT

Parameter Value Color Legend

User Defined
Line Defined
Survey Defined
Prospect Defined
Write-Up Defined

OK

Cancel

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Deconvolution Goals

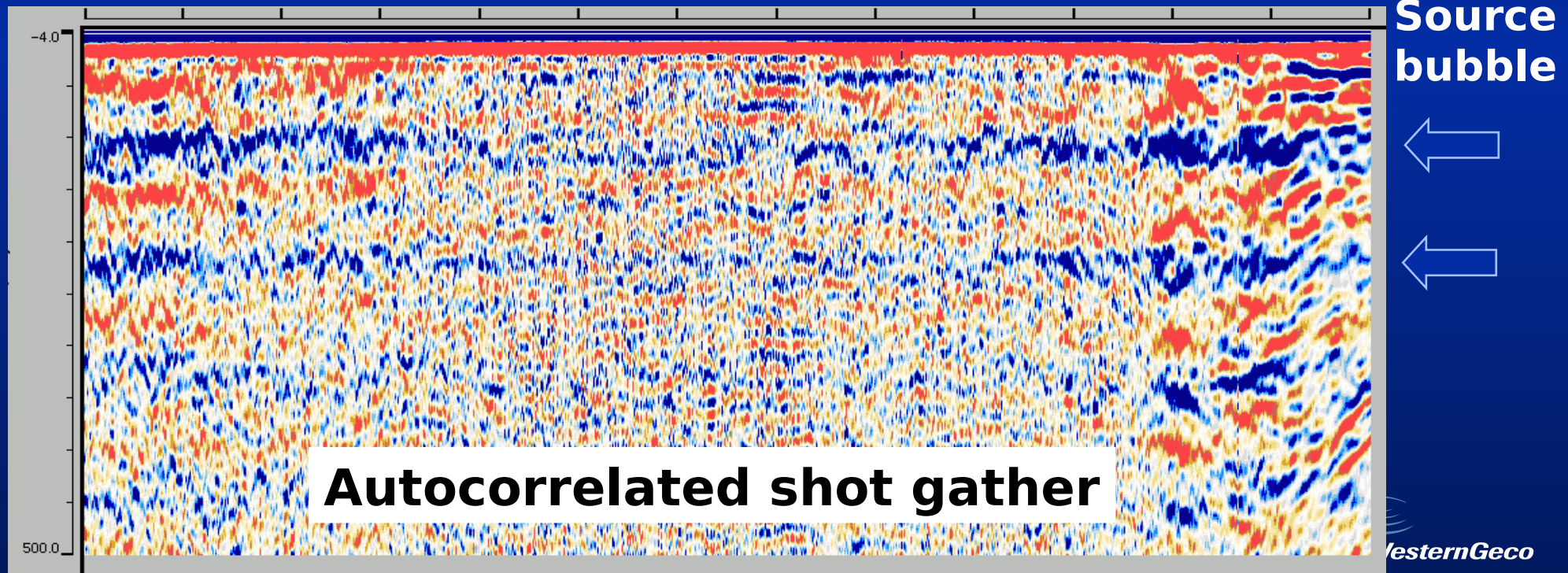
- **Decon can do several things**
 - **Compress the wavelet to a sharper, less reverberatory pulse**
 - **Remove multiples**
 - **Remove noise (or at least damp down its effects)**
- **Different objectives may require different, sometimes contradictory, parameterisation**
- **When testing decon, you need to know exactly what you want to achieve**

Pre-Stack Wavelet Compression

- **Pre-stack decon for wavelet compression**
 - **Apply geospread, check amplitude balance**
 - **Mute 1st breaks, or set START_TIME appropriately**
 - **Apply designature**
 - **Run autocorrelations, check for bubble pulse**
 - **Choose design window(s) - try to use single window**
 - **Choose length and gap(s) to test**
 - **length > bubble period (e.g.. 150 - 200 ms)**
 - **long gap (e.g.. 64 ms) if no wavelet shaping required, otherwise test various short gaps (e.g.. 4, 16, 24, 32, 48)**
 - **Test decon(s), test shot-averaging of “best” decon**

General deconvolution parameterisation

- Pre-stack decon for wavelet compression
 - Source bubble is consistent over all offsets, multiples are not
 - Decon operator needs to be longer than 1st reverberation



Summary

- Omega deconvolution
 - Very flexible
- General deconvolution parameterisation
 - Decon is a general purpose tool - more specialised programs will often be more appropriate
 - Parameterisation is complicated
 - Have a clear idea of what you want to achieve with decon
 - Careful testing pays dividends
 - Remember that deconvolution *'Design windows', 'Prediction distances', 'Active and total operators'* should all be integer multiples of the data sampling interval
- Always look at autocorrelations pre and post decon

Agenda

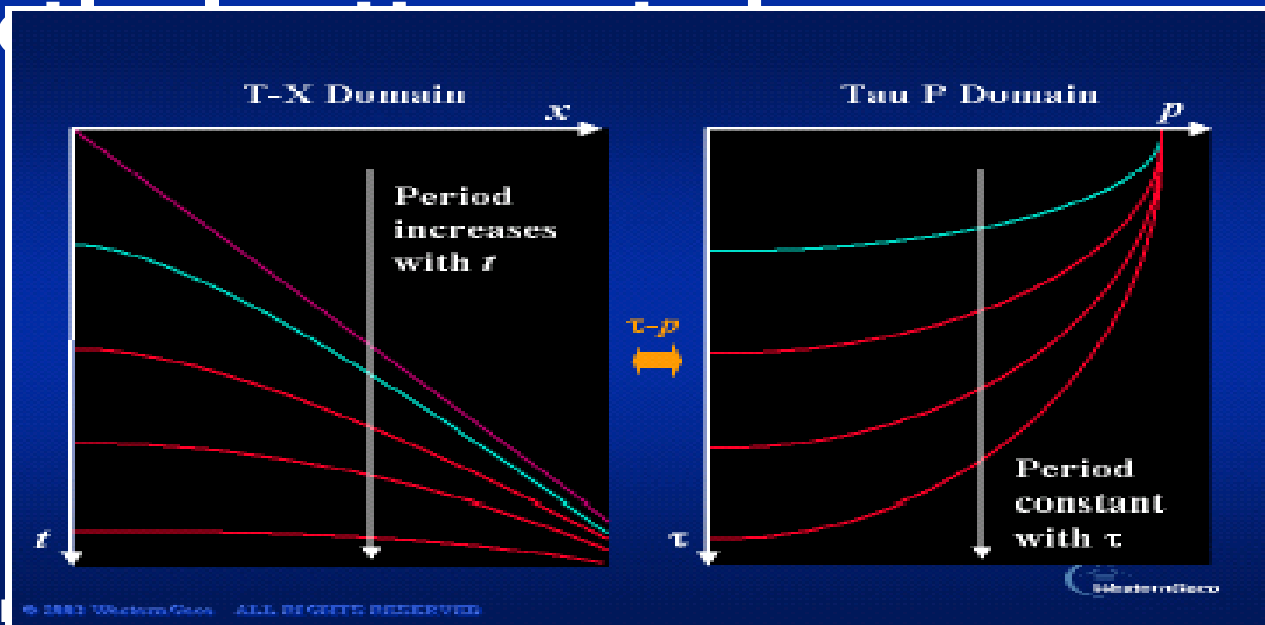
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- **Deconvolution SFM in Omega**
- **Conclusions**
- **Tau-P Demultiple**

Tau-P Demultiple

- It is becoming more & more common to perform Deconvolution in the Tau-P domain.
- Tau-P Dcon is essentially a multiple attenuation process
- Prestack input data is transformed from the T-X domain to the Tau-P domain. While in the Tau-P domain predictive trace by trace deconvolution is applied in order to attenuate predictable multiple energy.

Why Dcon in the linear Tau-P domain?

- In T-X domain water bottom multiples period varies in both time and offset.
- Deconvolution expects that the multiple period is constant within the design window. So these multiples are not effectively deconvolved.



Why Dcon in the linear Tau-P domain?

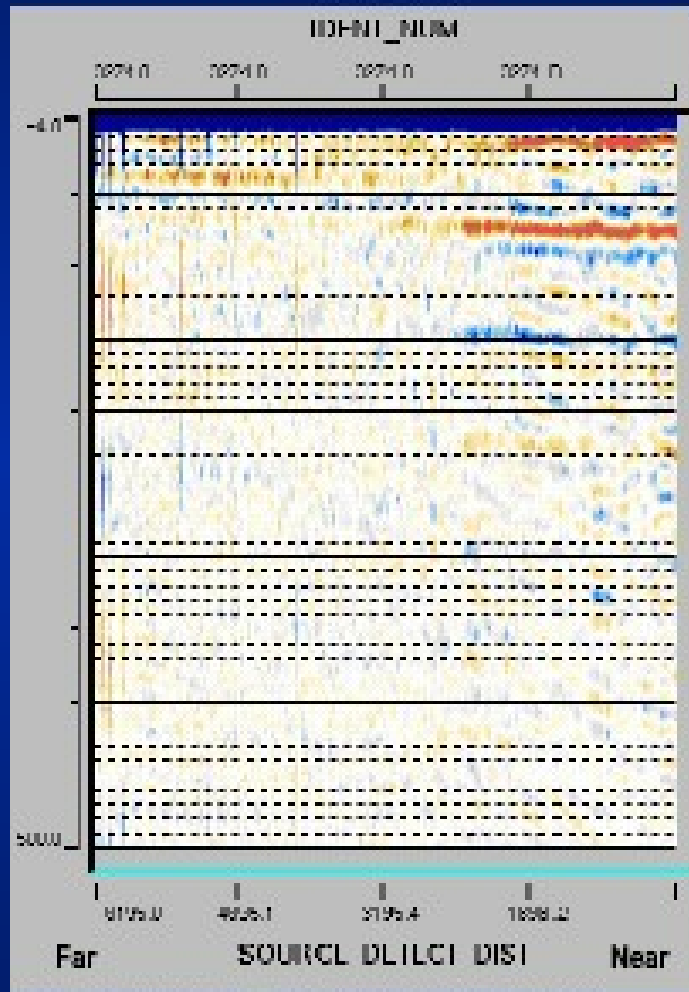
- Transforming the data into the Tau-P domain effectively splits the data into traces, which represent given time dips.

These traces contain multiple energy of a given period.

As the multiple energy is now periodic deconvolution will perform more effectively.

Why Dcon in the linear Tau-P domain?

Autocorrelated shot gather



Autocorrelated tau-p gather

